

GULF COAST NETWORK

ASSESSING THE RISK OF FOLIAR INJURY FROM OZONE ON VEGETATION IN PARKS IN THE GULF COAST NETWORK

October 2004

Objective

This assessment employs a biologically-based method to evaluate the risk of foliar injury from ozone at parks within the 32 Vital Signs Networks. The assessment allows resource managers at each park to better understand the risk of ozone injury to vegetation within their park and permits them to make a better informed decision regarding the need to monitor the impacts of ozone on plants.

This introduction provides an overview of the risk assessment process and the data used. It also provides a summary of the results of risk assessments for sites within the network.

Risk Assessment Methodology

The risk assessment is based on a Triad model that holds that the response of a plant to ozone is the result of the interaction of the plant, the level of exposure and the exposure environment. While interactions among the three variables determine the response, the state of any one of them can serve to accentuate or preclude the production of foliar injury. The response is greatest when all three variables and their interactions are optimized relative to the conditions that foster injury. The optimized states are: the species of plants are highly sensitive to ozone, the exposure levels of ozone significantly exceed the thresholds for foliar injury, and the environmental conditions foster gas exchange and the uptake of ozone by plants.

To conduct a risk assessment for a specific site, information was obtained on the ozone-sensitive plant species found there, the levels of ozone exposure that occur over a number of years, and, since soil moisture is a critical variable controlling gas exchange, the levels of soil moisture that exist during the periods of ozone exposure. The information was evaluated to determine the degree to which the levels of ozone exposure and soil moisture conditions integrate to create an environment that leads to the production of foliar injury on sensitive species at the site.

Ozone-Sensitive Plant Species

In 2003 a workshop was convened by the National Park Service to review the ozone research literature and apply the field experience of the attendees to develop a comprehensive list of ozone-sensitive plant species for the eastern and western United States. Because of the emphasis of previous field studies and research, information on the ozone-sensitivity of tropical, arctic and rare species is limited. The workshop

identified both sensitive and bioindicator species for ozone, and published its determinations in a National Park Service Report (U.S. National Park Service 2003). An ozone bioindicator species is one whose high level of sensitivity and characteristic pattern of foliar injury allow it to be confidently used to ascertain the occurrence of injurious levels of ozone exposure in the field. With regard to the Triad model, a bioindicator species integrates the effects of exposure and environment while optimizing plant sensitivity. A bioindicator serves as an early-warning agent for the plant community with respect to the potential impacts of ozone. Ozone-sensitive and bioindicator plant species at each site were identified by comparing the site's floral list from NPSpecies with the list of sensitive species developed at the workshop.

Levels of Ozone Exposure

Ozone exposure data for 1995 through 1999 for each site were obtained either from on-site monitoring or by kriging. Both monitored and kriged data have limitations. Ozone monitoring was conducted at relatively few sites, but provides the most accurate assessment of ozone exposure. However, data from a single monitor may not accurately represent exposures throughout a large park, or a park with significant elevation differences. For sites without monitoring, ozone data were statistically estimated using a technique known as kriging. This technique uses ozone data from near-by monitoring sites to estimate data for the point of interest. Most of the sites in the risk assessment have kriged data. The accuracy of the kriged data depends on the number of near-by monitoring sites, their distance and their spatial arrangement. The accuracy with which the kriged data represents the actual exposure conditions is likely to vary among the sites.

All ozone data, both monitored and kriged, were analyzed by the Air Resources Division of the National Park Service to produce annual indices of exposure for 1995 through 1999 for each site. Since the ozone research community has not completely accepted one index of exposure as fully characterizing the threshold for foliar injury to vegetation, the assessment employed three indices to assure a comprehensive approach was taken in the assessment.

One index is the Sum06 and its attendant thresholds for injury (Heck and Cowling 1997). This index is comprised of the 90-day maximum sum of the 0800 through 1959 hourly concentrations of ozone ≥ 60 ppb (0.60 ppm). The index is calculated over running 90-day periods and the maximum sum can occur over any period of the year, although the chemistry of ozone generation usually results in it occurring over the summer months. For risk assessment purposes, it is also necessary to know the three-month period over which each year's maximum index occurs.

Another index is the W126 and its associated thresholds (Lefohn et al. 1997). The W126 index is the weighted sum of the 24 one-hour ozone concentrations daily from April through October, and the number of hours of exposure to concentrations ≥ 100 ppb (0.10 ppm) during that period. The W126 index uses a sigmoidal weighting function in producing the sum: the lower concentrations are given less weight than are the higher concentrations since the higher exposures play a greater role in producing injury. The

significance of the higher concentrations is also reflected in the requirement that there be a specified minimum number of hours of exposure to concentrations ≥ 100 ppb. Thus, the W126 index has two criteria that must be realized to satisfy its thresholds: a minimum sum of weighted concentrations and a minimum number of hours ≥ 100 ppb.

The last indicator of ozone exposure, designated N-value, consists of the numbers of hours of exposure each year that exceeded 60, 80 and 100 ppb. While there are no formal thresholds associated with these values, they provide insight to the distribution of exposures among these concentrations, and to the numbers of hours at and above 80 and 100 ppb, levels of exposure that are associated with the production of foliar injury.

Soil Moisture Status

Although gas exchange in plants is influenced by many environmental variables, soil moisture status is a critical factor since stomatal closure during periods of low soil moisture can severely limit gas exchange. Since site-specific soil moisture data are not available for the sites, the USDA's Palmer Z Index was selected to represent soil moisture conditions. The Palmer Z Index is a measure of the short-term departure of soil moisture from the long-term mean for the area. Consequently, the index automatically takes into account the diversity in precipitation among the parks, and emphasizes the difference that exists between the monthly soil moisture norm for the site and its actual state. The index is calculated monthly for up to ten regions in each of the 48 contiguous states, and measures drought on a scale from 0.0 to -4.0 , a range representing normal to severe conditions. The regions are considered to be relatively homogeneous by USDA, but contain a diversity of soil, elevation and site variables that influence the soil moisture conditions at any specific location. The Palmer Z Index is not site specific and may not fully represent the soil moisture conditions at a park during a specific month.

The objective of this aspect of the risk assessment was to determine whether there is a consistent relationship between the level of ozone exposure and soil moisture status for the site by using the five years of data available. Atmospheric conditions that foster the production of ozone, such as clear sky, high UV levels and higher temperatures, are ones associated with the presence of few clouds and reduced precipitation. Consequently, years with high levels of atmospheric ozone may also experience low levels of soil moisture. This inverse relationship can constrain the uptake of ozone by plants in years with high levels of ozone and significantly reduce the likelihood that foliar injury will be produced. Knowing whether this relationship exists at a site is essential in determining whether certain levels of ozone exposure pose a risk to vegetation.

Palmer Z data were obtained from the USDA web site for 1995 through 1999 and tabulated for the three-month period over which the Sum06 exposure indices were compiled, and for the May to October period associated with the W126 exposure indices. Visual analysis of the exposure and soil moisture data was undertaken to determine whether there was an association between the two factors at each site.

Site-Specific Assessment

After information on the presence of sensitive species, levels of ozone exposure and relationships between exposure and soil moisture was compiled, it was synthesized into an assessment of risk of foliar injury for the site. Risk was classified as high, medium or low. Most sites had ozone-sensitive species on them and some of species were bioindicators that could be used in field surveys for ozone injury. If a site did not have any sensitive species, the risk assessment was completed and considered to be potential until sensitive species are identified.

The Sum06 and W126 exposure indices were examined to determine whether they exceeded their respective thresholds for injury, and the frequency with which the thresholds were exceeded over the five-year assessment period. The N-value data were examined to assess the distribution of exposures in a given year, and the consistency of exposure over the five years.

Evaluation of the relationship between ozone exposure and soil moisture might indicate they are inversely related, or they are not related and months of drought occur independent of the level of ozone exposure. At a site where exposure and drought are inversely related, the uptake of ozone is constrained by drought stress in the highest exposure years. In this instance, the risk of foliar ozone injury is likely greatest in years with lower levels of exposure that still exceed the injury thresholds and with soil moisture conditions that are more favorable for the uptake of ozone. In these cases, the greatest risk of foliar injury does not necessarily occur in the year with the highest level of ozone exposure. At sites where exposure and soil moisture are not related, the risk of foliar injury in a given year is a function of the random co-occurrence of high exposure and favorable moisture conditions.

The risk of foliar ozone injury at a site was determined by analyzing the plant, exposure and moisture data. The process was not quantitative, but based upon three primary evaluations: the extent and consistency by which the ozone injury thresholds were exceeded by the Sum06 and W126 exposure indices, the nature of the relationship between exposure and soil moisture, and the extent to which soil moisture conditions constrained the uptake of ozone in high exposure years. The evaluation of these factors and the assessment of their interactions with ozone-sensitive plant species is consistent with the Triad model of risk assessment, and comprises the framework for determining whether the risk of foliar ozone injury was high, moderate or low at each site. The accuracy of a site's risk assessment is dependent upon the quality of the plant list, the accuracy of the ozone exposure data and the degree to which the regional soil moisture data represent conditions at the site.

Sites receiving a risk rating of high have a probability of experiencing foliar injury in most years, while those rated low are not likely to experience injury in any year. A rating of moderate was assigned to sites where analysis indicated injury was likely to occur at some point in the five-year period, but the chance of injury occurring consistently was low. In other words, foliar injury will probably occur at sites rated moderate, but it is not

anticipated it will occur regularly or frequently. Sites rated moderate are likely to experience a wide temporal variation in the occurrence of injury, and over a period of time may experience injury for one or more years while also experiencing several years without injury.

Literature Cited

Heck, W.W. and E.B. Cowling. 1997. The Need for a Long-term Cumulative Secondary Ozone Standard - An Ecological Perspective. *Environmental Management*. January

Lefohn, AS, W Jackson, D. Shadwick, and HP Knudsen. 1997. Effect of surface ozone exposures on vegetation grown in the Southern Appalachian Mountains: identification of possible areas of concern. *Atmospheric Environment* 31(11):1695-1708.

U.S. National Park Service. 2003. Ozone Sensitive Plant Species on National Park Service and US Fish and Wildlife Service Lands. NPS D1522. Natural Resource Report NPS/NRARD/NRR-2003/01. Air Resources Division. Denver, CO. 21 pp. (Available at www2.nature.nps.gov/ard/pubs/index.htm)

SUMMARY OF RISK ASSESSMENTS FOR PARKS IN THE GULF COAST NETWORK

Park	Code	State	Risk	O3 Data
Big Thicket N PRES	BITH	TX	high	kriged
Gulf Islands NS	GUIS	FL	low	kriged
Jean Lafitte NHP & PRES	JELA	LA	moderate	kriged
Natchez Trace NST	NATR	MS	various	krig/monit
Padre Island NS	PAIS	TX	low	kriged
Palo Alto Battlefield NHS	PAAL	TX	low	kriged
San Antonio Missions NHP	SAAN	TX	moderate	kriged
Vicksburg NMP	VICK	MS	low	kriged

BIG THICKET NATIONAL PRESERVE (BITH)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for BITH					
	1995	1996	1997	1998	1999
Sum06	26	13	21	16	18
W126	39.6	18.5	28.2	25.0	24.3
N60	617	283	461	389	384
N80	213	74	121	114	106
N100	62	24	35	38	34

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at BITH					
	1995	1996	1997	1998	1999
Month 1	-0.06	-0.60	-0.49	-0.41	0.04
Month 2	0.90	0.09	2.46	3.40	-2.57
Month 3	-0.07	4.20	-1.22	3.15	-1.16

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at BITH					
	1995	1996	1997	1998	1999
April	1.79	-0.33	3.18	-1.73	-0.87
May	-0.19	-3.21	-0.69	-3.53	0.52
June	-0.06	-0.60	1.27	-3.59	1.20
July	0.90	0.09	-0.49	-4.04	0.04
August	-0.07	4.20	2.46	-0.41	-2.57
September	0.00	2.39	-1.22	3.40	-1.16
October	-1.55	-0.24	1.46	3.15	-0.76

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 and 80 ppb, and exceeded 100 ppb for a significant number of hours every year. These levels of exposure can injure vegetation.
- There does not appear to be any association between either the 90-day Sum06 or the seasonal W126 index of ozone exposure and soil moisture. Soil moisture levels during the 90-day Sum06 accumulation periods were generally normal and favored the uptake of ozone. One month of mild drought occurred in 1997, the second highest exposure year, and two months of mild and moderate drought occurred in 1999, a mid-level exposure year, otherwise soil moisture was normal over the five-year period. There is also no association between the seasonal W126 exposure index and soil moisture. There was one month of mild drought in the highest and second highest ozone years, 1995 and 1997 respectively. The mid-level exposure years, 1998 and 1999, had four and two months of mild to

severe drought respectively, while the lowest exposure year, 1996, had one month of severe drought.

The risk of foliar ozone injury to plants at Big Thicket National Preserve is high. While the levels of ozone exposure consistently create the potential for injury, dry soil conditions constrain the uptake of ozone and reduce the likelihood of injury in some years. Levels of exposure capable of producing foliar injury also occur in years with minor drought and normal soil moisture. The probability of foliar injury developing may be greatest during years such as 1995 and 1997 when ozone exposures exceed the thresholds, and soil moisture levels are under mild drought and do not significantly constrain the uptake of ozone.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: redbud, white ash, American sycamore, black cherry, and American elder.

GULF ISLAND NATIONAL SEASHORE (GUIS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
Liquidambar styraciflua	Sweetgum	Hamamelidaceae
Liriodendron tulipifera	Yellow-poplar	Magnoliaceae
Parthenocissus quinquefolia	Virginia creeper	Vitaceae
Pinus taeda	Loblolly pine	Pinaceae
Prunus serotina	Black cherry	Rosaceae
Rhus copallina	Flameleaf sumac	Anacardiaceae
Sambucus canadensis	American elder	Caprifoliaceae
Sassafras albidum	Sassafras	Lauraceae
Spartina alterniflora	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for GUIS					
	1995	1996	1997	1998	1999
Sum06	13	10	18	21	19
W126	23.6	23.5	29.0	34.6	34.3
N60	412	427	515	582	638
N80	52	34	67	127	90
N100	6	4	5	22	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at GUIIS					
	1995	1996	1997	1998	1999
Month 1	0.32	-0.69	0.77	-2.91	-0.55
Month 2	-0.55	1.76	-0.56	-4.34	-2.10
Month 3	0.15	0.52	-1.66	-1.34	1.67

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at GUIIS					
	1995	1996	1997	1998	1999
April	0.81	1.52	1.92	-1.48	-2.10
May	1.38	-1.70	1.62	-2.91	1.67
June	0.32	-0.71	1.20	-4.34	1.34
July	-0.55	-0.69	0.77	-1.34	0.75
August	0.15	1.76	-0.56	-2.40	-1.62
September	-1.50	0.52	-1.66	8.81	-1.92
October	3.49	2.85	1.53	-1.68	-0.46

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value exceeded the threshold each year, the N100 count shows that the required number of hours was met in two of the years, although concentrations exceeded 100 ppb every year. The criteria for injury under the W126 exposure index are generally not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had twenty-two hours in which the concentration exceeded 100 ppb, but there were generally six or fewer hours. These levels of exposure may injure vegetation in a high exposure year.
- Relationships between both the 90-day Sum06 and seasonal W126 accumulation period ozone levels and soil moisture appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low. This relationship reduces the uptake of ozone and the effectiveness of the higher exposures in producing foliar injury. The year with the highest Sum06 ozone exposure value, 1998, had three months of mild to severe drought stress. The next two highest ozone years, 1999 and 1997, each had one month of mild or moderate stress,

while the two lowest ozone years both had favorable moisture conditions. Soil moisture levels associated with the seasonal W126 index also appear inversely related to ozone concentrations. In the two years with the highest and similar levels of ozone, 1998 and 1999, soil moisture conditions were at moderate to severe drought levels for six and three months, respectively. In the three years with the lowest ozone exposures there was one month of mild drought each year.

The risk of foliar ozone injury at Gulf Island National Seashore is low. The threshold level for injury is consistently satisfied only by the Sum06 index, while the W126 index satisfies the criteria on occasion. The N-values indicate that there are occasional exposures to concentrations of ozone greater than 80 ppb, with a few hours of exposure to 100 ppb. The inverse relationship between exposure and soil moisture constrains the uptake of ozone in high exposure years and reduces the likelihood of foliar injury.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: yellow-poplar, black cherry, and American elder.

JEAN LAFITTE NATIONAL HISTORIC PARK AND PRESERVE (JELA)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Fraxinus pennsylvanica</i>	Green ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Rubus allegheniensis</i>	Allegheny blackberry	Rosaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae

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	<u>W126</u>	<u>N100</u>
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Ozone Exposure Data

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Ozone air quality data for JELA					
	1995	1996	1997	1998	1999
Sum06	21	15	17	16	21
W126	29.6	19.9	23.8	25.1	32.0
N60	510	359	421	438	573
N80	110	45	60	78	117
N100	13	4	5	13	7

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

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Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at JELA					
	1995	1996	1997	1998	1999
Month 1	-0.53	-2.58	2.29	2.16	-3.20
Month 2	3.20	0.84	-1.53	0.02	-0.24
Month 3	-0.58	0.41	-3.11	-3.34	3.74

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at JELA					
	1995	1996	1997	1998	1999
April	-0.53	-0.32	1.29	0.02	-3.20
May	3.20	-2.58	2.25	-3.34	-0.24
June	-0.58	0.84	0.65	-1.86	3.74
July	0.36	0.41	2.29	-2.25	-0.38
August	-1.38	0.52	-1.53	-1.35	-2.08
September	-2.89	-0.44	-3.11	7.52	-0.86
October	-0.49	-0.68	-0.71	-0.94	1.44

Risk Analysis

- There are several ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. The W126 accumulative value exceeded the threshold each year and the N100 count shows that the required number of hours was met in three of the years. The criteria for injury under the W126 exposure index are generally satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. Some years had a greater number of hours above 80 and 100 ppb. Two years had thirteen hours in which the concentration exceeded 100 ppb, while the others had seven or fewer. These levels of exposure may possibly injure vegetation in high exposure years.
- Relationships between the 90-day Sum06 accumulation period ozone levels and soil moisture are difficult to assess because ozone exposures were relatively consistent over the five years. Months of mild to severe drought were distributed over four of the years without respect to the ozone level, and one year had no drought months. There does not appear to be any association between the Sum06 level of ozone exposure and soil moisture status. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence

of drought. The highest and second highest ozone years, 1999 and 1995, had two months of mild moderate drought, and the mid-exposure year, 1998, had four months of mild to severe drought. The second lowest exposure year, 1997, had two months of mild to severe drought, and the lowest year, 1996, had one month of moderate drought.

The risk of foliar ozone injury at Jean Lafitte National Historic Park and Preserve is moderate. The threshold level for injury is consistently satisfied by the Sum06 index and generally by the W126 index. The N-values indicate there are frequent exposures to concentrations of ozone greater than 80 ppb and 100 ppb in some years, with considerably less exposure in other years. The levels of ozone and soil moisture show no association, and suggest that conditions limiting the uptake of ozone occur for several months during most years. It is anticipated that the risk of injury may be greatest in years such as 1995 when ambient levels of ozone exceed injury thresholds and soil moisture conditions generally favor uptake by plants.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: American sycamore, black cherry, Allegheny blackberry, and American elder.

NATCHEZ TRACE NATIONAL SCENIC TRAIL (NATR)

A stand-alone risk assessment was prepared for the Natchez Trace National Scenic Trail. The assessment evaluates the risk of foliar injury at nine sites along the Trail.

PADRE ISLAND NATIONAL SEASHORE (PAIS)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Spartina alterniflora</i>	Smooth cordgrass	Poaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for PAIS					
	1995	1996	1997	1998	1999
Sum06	11	5	6	11	14
W126	27.6	11.7	11.1	13.7	16.1
N60	465	197	182	247	283
N80	96	32	17	31	45
N100	16	4	1	3	2

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PAIS					
	1995	1996	1997	1998	1999
Month 1	-0.15	-1.99	3.13	1.63	-1.71
Month 2	0.20	-1.07	2.03	-1.66	-0.69
Month 3	-0.83	-1.49	2.85	-4.03	-1.87

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PAIS					
	1995	1996	1997	1998	1999
April	-1.53	-1.49	3.13	-1.66	-2.21
May	-0.67	-3.61	2.03	-4.03	-1.60
June	-0.56	-2.04	2.85	-2.84	0.69
July	-1.48	-1.23	-1.87	-2.52	-0.04
August	-0.15	2.45	-2.18	3.50	2.33
September	0.20	-0.93	-1.43	0.43	-1.71
October	-0.83	-1.68	1.65	3.29	-0.69

Risk Analysis

- There is one ozone-sensitive species listed for the site.
- The Sum06 index intermittently exceeds the threshold for injury. While the W126 accumulative value exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had sixteen hours in which the concentration exceeded 100 ppb, but the remainder had four or fewer hours. The highest level of exposure may possibly injure vegetation.
- There appears to be no relationship between either the 90-day Sum06 or seasonal W126 accumulation period ozone levels and soil moisture conditions. For the Sum06 index, months of drought were distributed over three of the years without respect to the ozone level, and two years had no drought. The year with the highest ozone, 1999, had two months of mild drought while the year with the lowest ozone, 1996, had three months of mild drought. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. Each year experienced two to five months of mild to severe drought stress. The highest ozone year, 1995, had two months of mild stress, while the

second highest year, 1999, had three months of mild and moderate drought. The intermediate ozone year, 1998, had three and four months of mild to severe drought, and the lowest ozone years, 1996 and 1997, had five and three months of mild to severe drought, respectively.

The risk of foliar ozone injury to plants at Padre Island National Seashore is low. The Sum06 and W126 exposure indices are either marginally or not satisfied, and exposure to concentrations over 100 ppb is generally rare. There are three or more months of mild and moderate drought in most years. These levels of soil moisture constrain the uptake of ozone and reduce the likelihood of foliar injury. There are no ozone bioindicator species at the site.

PALO ALTO BATTLEFIELD NATIONAL HISTORIC SITE (PAAL)

Plant Species Sensitive to Ozone

There are no ozone-sensitive species listed for the site.

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

<u>Ozone air quality data for PAAL</u>					
	1995	1996	1997	1998	1999
Sum06	4	2	3	10	8
W126	13.4	5.8	6.5	9.7	7.8
N60	227	93	88	170	130
N80	33	9	6	10	8
N100	6	2	1	1	0

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at PAAL					
	1995	1996	1997	1998	1999
Month 1	-1.93	-0.40	-2.29	0.79	-0.65
Month 2	-0.67	-2.70	-1.16	-0.98	-1.44
Month 3	-1.96	-1.47	5.70	-2.94	-1.58

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at PAAL					
	1995	1996	1997	1998	1999
April	-0.81	-0.40	4.37	-0.98	-1.61
May	-1.93	-2.70	1.43	-2.94	-0.96
June	-0.67	-1.47	-0.33	-3.08	-1.01
July	-1.96	-2.48	-1.65	-2.37	1.78
August	2.79	1.71	-2.29	-1.92	1.61
September	-1.70	-0.60	-1.16	3.28	-0.65
October	2.86	2.09	5.70	3.58	-1.44

Risk Analysis

- There are no ozone-sensitive species listed for the site.
- The Sum06 index is generally below the threshold for injury to vegetation. While the W126 accumulative value generally exceeds the threshold, the N100 count shows that the one-hour concentration of ozone fulfilled the W126 threshold in only one year, and thus the criteria for injury under the W126 exposure index are not satisfied. The Sum06 and W126 indices are generally below the levels considered necessary for injury to vegetation.
- The N-values for the site show concentrations frequently exceeded 60 ppb and exceeded 80 ppb for a few hours each year. No year had more than three hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- No relationship is apparent between either the 90-day Sum06 or W126 seasonal accumulation period levels of ozone and soil moisture. For the Sum06 index this is a consequence of the consistently low levels of exposure at the site and the regular distribution of drought over the five-year period. Each year experienced one or two months of mild and moderate drought that occurred without any relationship to the level of ozone. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought; each of the five years had three or four months of drought. The highest ozone year, 1999, and the lowest ozone years, 1996 and 1997, each experienced three months of mild and moderate drought.

The risk of foliar ozone injury to plants at Palo Alto Battlefield National Historic Site is low. This is the result of the low levels of ozone, and the reduction in the uptake of ozone that occurs as a result of several months of low soil moisture each year. No ozone-sensitive species have been identified at the site.

SAN ANTONIO MISSIONS NATIONAL HISTORIC PARK (SAAN)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for SAAN					
	1995	1996	1997	1998	1999
Sum06	11	3	7	15	15
W126	35.6	12.9	19.2	20.2	26.0
N60	580	195	322	352	447
N80	159	43	64	56	93
N100	30	9	7	8	9

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at SAAN					
	1995	1996	1997	1998	1999
Month 1	-0.22	-1.62	3.27	-1.28	0.72
Month 2	0.68	-4.14	0.23	-3.12	-0.33
Month 3	-1.17	-1.28	-0.97	-3.17	-1.91

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at SAAN					
	1995	1996	1997	1998	1999
April	0.11	-1.62	3.31	-1.28	-1.32
May	1.14	-4.14	1.70	-3.12	-0.24
June	0.78	-1.28	3.27	-3.17	0.98
July	-0.22	-2.91	0.23	-2.70	0.72
August	0.68	2.69	-0.97	2.86	-0.33
September	-1.17	0.43	-0.59	1.64	-1.91
October	-0.38	-1.86	4.25	7.36	-1.44

Risk Analysis

- There are a few ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index intermittently exceeds the threshold for injury. The W126 accumulative value and the N100 count are greater than their threshold values, thus the criteria for injury under the W126 index are satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. One year had thirty hours in which the concentration exceeded 100 ppb, but the remainder had nine or fewer hours. The higher levels of exposure may injure vegetation.
- No relationship is apparent between the 90-day Sum06 accumulation period levels of ozone and soil moisture. The years with the highest and lowest ozone exposures, 1998 and 1996 respectively, each experienced three months of mild and severe drought. The other years had either a month of mild drought or favorable conditions. Similarly, there is no association between the seasonal W126 level of ozone exposure and the incidence of drought. The highest ozone year, 1995, had one month of mild drought and the lowest year, 1996, experienced five months of mild and severe drought. Years with intermediate ozone exposures had favorable moisture conditions or several months of mild to

severe drought.

The risk of foliar ozone injury at San Antonio Missions National Historic Park is moderate. The Sum06 and W126 indices both satisfy their thresholds for injury. Although there is considerable variation among years, there are frequent exposures to ozone greater than 80 ppb and occasional exposures to concentrations greater than 100 ppb. The ability of low soil moisture to decrease the uptake of ozone is important at the site since there are often several consecutive months of mild and moderate drought. These levels of soil moisture constrain the uptake of ozone and reduce the likelihood of foliar injury. The co-occurrence of higher levels of ozone and of soil moisture conditions that favor uptake, such as in 1995 and 1997, increase the likelihood of injury in a given year.

A program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, American sycamore, and American elder.

VICKSBURG NATIONAL MILITARY PARK (VICK)

Plant Species Sensitive to Ozone

<i>Latin Name</i>	<i>Common Name</i>	<i>Family</i>
<i>Ailanthus altissima</i>	Tree-of-heaven	Simaroubaceae
<i>Cercis canadensis</i>	Redbud	Fabaceae
<i>Fraxinus americana</i>	White ash	Oleaceae
<i>Liquidambar styraciflua</i>	Sweetgum	Hamamelidaceae
<i>Liriodendron tulipifera</i>	Yellow-poplar	Magnoliaceae
<i>Parthenocissus quinquefolia</i>	Virginia creeper	Vitaceae
<i>Pinus taeda</i>	Loblolly pine	Pinaceae
<i>Platanus occidentalis</i>	American sycamore	Platanaceae
<i>Prunus serotina</i>	Black cherry	Rosaceae
<i>Robinia pseudoacacia</i>	Black locust	Fabaceae
<i>Sambucus canadensis</i>	American elder	Caprifoliaceae
<i>Sassafras albidum</i>	Sassafras	Lauraceae

Representative Ozone Injury Thresholds

Sum06 -- The running 90-day maximum sum of the 0800-2000 hourly ozone concentrations of ozone equal to or greater than 0.06 ppm. Index is in cumulative ppm-hr.

Natural Ecosystems	8 - 12 ppm-hr (foliar injury)
Tree Seedlings	10 - 16 ppm-hr (1-2% reduction in growth)
Crops	15 - 20 ppm-hr (10% reduction in 25-35% of crops)

W126 -- A cumulative index of exposure that uses a sigmoidal weighting function to give added significance to higher concentrations of ozone while retaining and giving less weight to mid and lower concentrations. The number of hours over 100 ppb (N100) is also considered in assessing the possible impact of the exposure. The W126 index is in cumulative ppm-hr.

	<u>W126</u>	<u>N100</u>
Highly Sensitive Species	5.9 ppm-hr	6
Moderately Sensitive Species	23.8 ppm-hr	51
Low Sensitivity	66.6 ppm-hr	135

Ozone Exposure Data

Ambient concentrations of ozone were not monitored on-site, but were estimated by kriging, a statistical interpolation process. The estimated hourly concentrations of ozone were then used to generate annual exposure values for the site. The exposure values include the Sum06 and W126 exposure indices in ppm-hr and the annual number of hours above 60, 80 and 100 ppb (N60, N80 and N100, respectively).

Ozone air quality data for VICK					
	1995	1996	1997	1998	1999
Sum06	18	15	17	13	16
W126	27.5	22.7	25.5	28.5	31.4
N60	521	411	490	525	600
N80	46	34	31	68	59
N100	1	1	1	4	3

Soil Moisture Status

The uptake of ambient ozone by a plant is highly dependent upon the environmental conditions under which the exposure takes place, and the level of soil moisture is an important environmental variable controlling the process. Understanding the soil moisture status can provide insight to how effective an exposure may be in leading to foliar injury. The Palmer Z Index was selected to indicate soil moisture status since it represents the short-term departure of soil moisture from the average for each month for the site. The objectives of the assessment were to examine the relationship between high annual levels of ozone and soil moisture status, and to consider the impact reduced soil moisture status would have on the effectiveness of exposure.

The Palmer Z Index is calculated for up to 10 regions within a state and therefore is not a site-specific index. Without site-specific data, ozone/soil moisture relationships can only be estimated. Site-specific criteria such as aspect, elevation, and soil type can alter soil moisture conditions such that they depart from those determined for the region. However, in lieu of site-specific data, the Palmer Z Index is the best estimate of short-term soil moisture status and its change throughout the growing season.

Palmer Z data were compiled for the site for both the three months used to calculate the Sum06 index and for the April through October period for the W126 index for 1995 through 1999. It was not possible to identify the specific 3-month summation period for the Sum 06 index since the index was obtained by kriging. The summation period was estimated from the 3-month periods for Sum 06 indices calculated from monitored ozone data for sites within 50 km of the park. The Palmer Z index ranges from approximately +4.0 (extreme wetness) to -4.0 (extreme drought) with ± 0.9 representing normal soil moisture.

Soil moisture status for the Sum06 index period.

Palmer Z Index data for 3-month Sum06 period at VICK					
	1995	1996	1997	1998	1999
Month 1	-1.48	2.05	-1.34	-0.06	-2.45
Month 2	-0.11	-0.83	0.16	-2.44	0.39
Month 3	-0.95	2.11	-1.29	0.98	-0.35

Soil moisture status for the April through October period for the W126 index.

Palmer Z Index data for the 7-month W126 period at VICK					
	1995	1996	1997	1998	1999
April	2.00	0.82	3.69	0.53	-1.91
May	-0.12	-1.63	0.91	-3.30	-1.29
June	-1.48	2.05	2.11	-2.76	0.30
July	-0.11	-0.83	-1.34	-0.06	-0.37
August	-0.95	2.11	0.16	-2.44	-2.45
September	-0.87	1.55	-1.29	0.98	0.39
October	1.02	0.37	1.48	-1.40	-0.35

Risk Analysis

- There are numerous ozone-sensitive species at the site, some of which are bioindicators for ozone.
- The Sum06 index exceeds the threshold for injury to vegetation. While the W126 accumulative value is above the threshold, the N100 count is below the required number and thus the criteria for injury are not satisfied.
- The N-values for the site show concentrations frequently exceeded 60 ppb and occasionally exceeded 80 ppb. No year had more than four hours in which the concentration exceeded 100 ppb. These levels of exposure are not likely to injure vegetation.
- Ozone exposures were similar over the five-year period, and no relationship is apparent between the 90-day Sum06 levels of ozone and soil moisture. Four of the five years experienced one or more months of drought, and only 1996 had favorable conditions. The years with the highest and lowest ozone exposures, 1995 and 1998, experienced one month of mild and moderate drought, respectively. Soil moisture levels associated with the seasonal W126 index appear to be inversely related to ozone concentrations: when ozone is high, soil moisture is low, although the pattern is not consistent. This relationship reduces the uptake of ozone and the effectiveness of the higher exposure in producing

foliar injury. The highest ozone year, 1999, had three months of mild to moderate drought stress. The next two highest ozone years, 1998 and 1995, had similar levels of ozone, but experienced four months of mild to severe drought and one month of mild drought, respectively. The two years with the lowest ozone, 1996 and 1997, had one and two months of mild drought respectively.

The low levels of ozone exposure and the frequent low soil moisture conditions at Vicksburg National Monument Park make the risk of foliar ozone injury to plants low. While the Sum06 index exceeds the threshold levels for injury, the W126 does not since the N100 criterion is generally not satisfied. There are occasional exposures to concentrations of ozone above 80 ppb, and rare exposure to 100 ppb. Soil moisture conditions of moderate to severe drought reduce the effectiveness of the higher concentration exposures.

If the level of risk increases in the future, a program to assess the incidence of foliar ozone injury on plants at the site could use one or more of the following bioindicator species: tree-of-heaven, redbud, white ash, yellow-poplar, American sycamore, black cherry, and American elder.